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Engineering Aspects of Waterborne Outbreak Investigation

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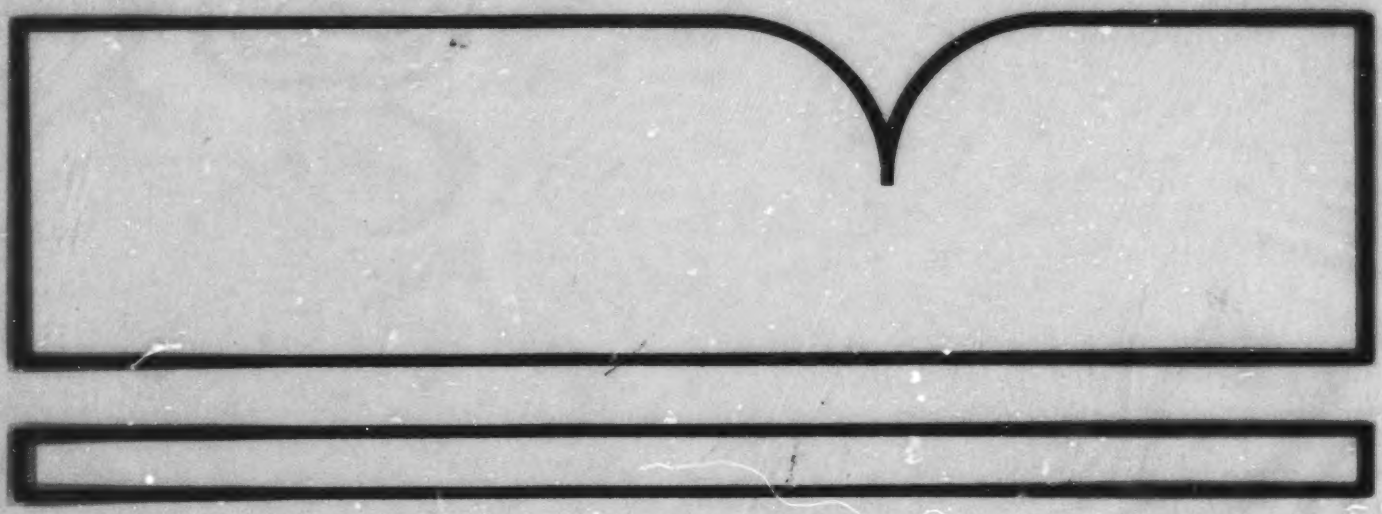

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ENGINEERING ASPECTS OF WATERBORNE OUTBREAK INVESTIGATION

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16. ABSTRACT

The subject material in this manuscript covers the engineering aspects of waterborne outbreak investigation. Major areas included in this discussion are: evaluation of disinfection (concentration and contact time, pH and temperature, interference); evaluation of the water system itself (source of supply, treatment, distribution network); sampling for the agent; and communication.

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I. INTRODUCTION

In most cases waterborne disease outbreak investigations are difficult to conduct. An investigation is made difficult because normally the outbreak has subsided by the time an investigation is started. If a water system is challenged by a pathogen and cannot respond to the challenge, an exposed susceptible person will generally become ill in 24-72 hours for most bacterial/viral agents, or one to three weeks for parasitic agents, or two to six weeks for hepatitis A virus. The ill person may suffer with his illness several days before seeking medical treatment at which time a doctor or nurse who has seen a number of patients with similar symptoms may recognize that an outbreak is in progress. They may report the unusual number of illnesses to government authorities who before beginning an investigation may require several days to determine whether the cases constitute an outbreak or are sporadic and whether the preliminary data indicate a possible common source. Thus, depending on the causative agent and respective incubation period, a week to several weeks may elapse between the exposure and the beginning of an investigation. These delays contribute to failure in identifying the causative agent, especially from water samples, since the contaminant may be purged from the distribution system through normal usage of water; in reconstructing events that permitted contamination to occur; and in specifically identifying the event or defect that caused contamination.

Besides being hindered by delays in initiating an investigation, the engineering studies are further hampered because clues and information developed by the epidemiologist through interviews with cases and controls do not become available in usable form for three to five days. Complaints of odorous or strange tasting water, especially if time and place are identified, are

clues which are helpful in the engineering investigation. Attack rates also can be very useful if they are stratified by a common zone of the distribution network. High attack rates in a specific zone may lead the engineer to suspect localized contamination introduced through a cross-connection, main break, open reservoir, or a well that serves as a source of supply for one area of the community.

Because of the delays inherent in beginning outbreak investigations and the time required to develop reliable epidemiological evidence to confirm that illness is transmitted via water, the engineer must after a preliminary assessment of the situation assume that drinking water is the cause and must act quickly. To err is human but failure to act in preventing further illness is rarely forgiven. Therefore, the engineering investigation should consider as the first order of priority an evaluation of the treatment currently provided for water to assure that it is capable of responding to challenge by the suspected agent. The most critical water treatment process in combating infectious agents is disinfection, and a thorough evaluation of disinfection practices should be undertaken immediately. In most situations where groundwater is used as a source of supply, disinfection will be the only treatment. Where surface water is used complementary processes including mixing, coagulation-flocculation, sedimentation, and filtration normally will be provided along with disinfection. The complementary processes are important for preparing water for disinfection, but disinfection is the primary treatment for inactivation of bacteria, viruses, and parasites.

After disinfection has been evaluated and adjusted to neutralize the suspected microbiological challenge, the engineer must choose his second

priority. The choice is based upon the continued occurrence of illness. If new cases are seeking medical attention and this reporting is apparent to physicians, health clinics, and hospitals, it may mean the agent is still present in the water system. The second priority should then be the collection of water samples to capture and identify the agent. If the same agent is identified from both water samples and clinical specimens from ill cases, the required water system improvements are implemented quickly and with few objections.

If there are no recent reports of illness, the engineer's second priority should be a thorough evaluation of the entire water system to determine weaknesses and strengths in facilities and operations (collection of water samples becomes the third priority). This information is not only useful to the engineer but also is important to the epidemiologist in designing population surveys of households served by the water system. Knowledge of the treatment and distribution of water within a community and its environs is extremely important to the epidemiologist in selecting the survey sample. For example, one segment of the community may receive treated water while another may receive untreated water, and the survey should be designed accordingly. Also, it is to the engineer's advantage to receive as soon as possible survey data from the epidemiologist on the location of the cases. For example, if 85 percent of the illness occurred in the northeast quadrant of the distribution network, the engineering evaluation should focus on determining what is unusual about the treatment and delivery of water in that quadrant. The date cases occurred is important to establish the timing of contamination or an event that caused contamination. The epidemiologist through a survey and/or questionnaire determines the date of onset of illness, symptoms of

illness, incubation period, diet histories, probable etiologic agent, and the time, person, and place associations to identify the vehicle of transmission. The collection and analysis of these data provides important clues for the engineer, particularly the graphing of cases of illness according to their date of onset (the epidemiological curve or epi-curve). From the epi-curve the engineer can derive an appropriate time of exposure by subtracting the incubation period for the illness from the median date of onset of all ill persons. This provides a good estimate of the critical time period for contamination of the system, and information should be obtained on how the operation, maintenance, and control of the water system relate to that time. It should be obvious that the engineer and epidemiologist are important to each other in sharing information obtained early in the investigation of the outbreak.

The fourth priority of the investigation is related to communication in that information collected and analyzed through the engineer's participation must be dessiminated. He must communicate not only with the epidemiologist but also with the water utility, local governing bodies, and the public both during the investigation and afterwards. During the investigation communication to the utility and local government will primarily be verbal; afterwards it will be a detailed written report intended to present findings of the evaluation and recommendations for improvement of the water system. Both forms of communication are important and the principles of disseminating oral and written information should be followed. Communication with the public will be accomplished primarily through newspapers, television, and radio. In some instances it is more efficient to communicate findings to a central authority who has previously been designated as an official spokesperson.

The discussion which follows focuses on waterborne disease outbreaks caused by microbiological agents. Engineering aspects of outbreaks caused by chemical agents were not specifically addressed because: chemical poisonings constitute a small percentage of the total number of outbreaks; normally chemical agents are easily recognized because they impart color, taste, or odor which consumers detect and report; and in most cases, these outbreaks are brought under control rapidly through identification of the contaminant and isolation of the source of contamination. The acute health effects of exposure to chemical agents also contributes to identification and early control of outbreaks. The incubation period for acute effects is brief for ingested chemicals. They normally affect the upper gastrointestinal tract causing vomiting and symptoms not associated with microbiological agents, such as tingling of the skin, irritation of eyes and other membranes, vertigo, etc. Current technology for analysis of water for organic and inorganic constituents through gas chromatography and atomic absorption spectrophotometry permits rapid identification of contaminants. Once the contaminant is identified the source of contamination can generally be located quickly through association with use or manufacture of the chemical. Control of the source of contamination does not usually involve adjustments in water treatment but is directed towards isolation, containment, or cessation of discharge. If the contaminant cannot be controlled at the source, alternatives to adjustment in water treatment are normally chosen, and these alternatives include use of other sources of supply. Cross-connections, backsiphonage, corrosion of plumbing, and chemical-feed problems also have caused acute illness due to high concentrations of chemicals in the water system and should be considered during the investigation of an outbreak caused by chemical contaminants.

II. EVALUATION OF DISINFECTION (Priority No. 1)

The most important aspect of treatment is its capability to withstand challenge by a contaminant. Regardless of whether or not the epidemiologic study has confirmed that illness is related to drinking water, the engineer is responsible during the investigation to ensure that treatment is optimized with the primary objective of preventing the transmission of disease to preserve and protect public health.

The unit process having the greatest impact on reducing microbial challenge and preventing waterborne disease transmission is disinfection. In the United States the most commonly used disinfectant is chlorine. The dosage of chlorine is normally easy to adjust and in some circumstances chlorine contact time can be increased by simply relocating the injection point. No other unit process can reduce microbial concentrations on the order of four or five orders of magniture by simply adjusting the chemical dosage. Therefore, evaluating chlorination is the first order of business for the engineer.

The factors which influence the effectiveness of chlorination to inactivate bacteria, viruses, and parasites are: (1) concentration, (2) contact time, (3) pH, (4) temperature, and (5) interfering substances. Each of these factors must be evaluated to determine disinfection capability under current operating conditions and the adjustments that are necessary to cope with the challenge of a pathogen.

A. Concentration and Contact Time

The product of chlorine concentration (C) and contact time (T) produces a CT relationship which is used in determining the requirements for inacti-

vation of bacteria, virus, and protozoa. Since CT relationships are developed through laboratory research under carefully controlled conditions, applying the data to a real world situation requires engineering judgement. The CT values listed in Table 1 for virus were developed by White[1] and also can be applied for inactivation of bacterial agents. The viral CT values are based upon inactivation of coxsackie A2 virus which are more resistant than polio virus or any pathogenic vegetative bacteria implicated as causative agents in waterborne disease outbreaks. Values for protozoan CT were interpreted from the research conducted by White;[1] Jarrol, Bingham, and Meyer;[2] and Rice, Hoff, and Schaefer.[3] It is important to note from the CT relationships at the pH of 7 to 8, which are values common to most water systems, a rule-of-thumb can be applied. Systems using groundwater as a source of supply should apply a minimum CT of 15-30 to provide for viral and bacterial inactivation since they are generally the contaminants of concern; i.e., the size of viral particles permits easier penetration of strata overlying aquifers while protozoan cysts are trapped and retained. (Protozoan cysts are about 1000 times larger than virus particles.) Systems using surface water, especially those located in areas where source waters attain low temperatures of 5°C should apply a minimum CT of 100-150 for protozoan inactivation (at temperatures less than 5°C, the CT requirements will increase). Figure 1 graphically depicts the CT requirements included in Table 1.

With the CT value known, the contact time is determined through evaluation of the treatment facility, and the required chlorine concentration determined mathematically. Determination of the contact time should be done carefully, for there are several factors that should be considered. A commonly made mistake is using hydraulic displacement calculations to compute contact

time. For example, a one MG rectangular storage tank with inflow and outflow at opposite ends provides 2.4 hours of contact time when calculations consider the average daily plant output of 10 MGD, but the contact time actually provided may approach one-fourth of this calculated value.[4] With an actual contact time of 36 minutes, the chlorine concentration based on 2.4 hours contact time would be insufficient. This difference in the calculated displacement or theoretical retention (contact) time and the actual retention (contact) time stems from short-circuiting and dead spaces that are common to both rectangular and circular storage tanks. The use of the average daily plant output also can lead to errors. Plant output varies with customer demands which change during the day; peaks occur in the morning and evening. Peak daily demands for some systems can be double the average daily plant output and if this is the case the contact time is underestimated by an additional 50 percent. If the chlorinator is not paced to respond to changes in plant output, fluctuation in demand must be taken into consideration when evaluating contact time.

The preferred method of obtaining contact time is to conduct a tracer test. A simple and quick method is to increase the chlorine feed and determine chlorine residual concentrations of the basin effluent. The initial increase in concentration signals the flow-through time for a fraction of the plant output, and subsequent samples will reflect a steady rise in chlorine residual until the total incremental dosage has been accounted for. The mixed flow and dead space components of basin hydraulics also can be estimated through application of the tracer methods discussed by Hudson.[5] Another simple and quick method for tracer tests is to cease fluoride feed and read the decrease in fluoride concentration over time. The initial decrease in fluoride concen-

tration signals the flow-thru time for a fraction of plant output and represents the contact time provided for a portion of the basin volume. The advantage of using chlorine and fluoride as tracers is that there is no need to introduce a dye, salt, or other chemical that may require special permission to introduce into a water system and may cause concern over its toxicity. Decreasing the concentration of fluoride or increasing the concentration of chlorine for a short time should not cause objections to conducting the test. The elapsed time between the increase or decrease of chemical dosage and the initial corresponding change in the basin effluent represents the contact time, and should be used in the CT relationship to calculate the concentration of chlorine which will be required to achieve a microbiocidal residual. CT relationships are based upon maintaining the chlorine concentration for the entire contact time so the dosage must be adjusted accordingly to compensate for chlorine demand and dissipation.

Tracer tests are normally not required where transmission or distribution mains are depended upon for contact time. The mains are pressurized and under full-flow conditions the hydraulic conditions approximate plug flow. With plug-flow the theoretical and actual contact times are equivalent. However, they can be checked easily by increasing the chlorine dosage and measuring for the increase in residual at an appropriate downstream location. Table 2 provides a ready reference for computing contact time in transmission and distribution mains. By dividing the plant output or flow into the pipe capacity adjusted for length available, the contact time can be determined. For example, at a plant output of one MGD and 1000' of 24" pipe available, the contact time would be 34 minutes.

B. pH and Temperature

The effectiveness of chlorine as a disinfectant is influenced by the pH and temperature of the water being dosed. The pH determines the amount of hypochlorous acid (HOCl) and hypochlorite ion (OCl^-) in solution. HOCl is the predominant form at the lower pH's (pH 6 - 7.5) and OCl^- is the predominant form at higher pH's (pH 8 - 10). At pH 7 and 0°C, the dissociation of chlorine produces 83.3 percent HOCl and 16.7 percent OCl^-; at pH 9, 4.5 percent HOCl and 95.5 percent OCl^- are formed. It is important to know the dissociated forms of chlorine present at various pH values because HOCl is the form which possesses the destructive power as a microbiocide. According to White[1] "the germicidal efficiency of HOCl is due to the relative ease with which it can penetrate cell walls. This penetration is comparable to that of water, and can be attributed to both its modest size (low molecular weight) and its electrical neutrality (absence of an electrical charge)." White[1] states that the hypochlorite ion "is a relatively poor disinfectant because of its inability to diffuse through the cell wall of microorganisms due to the negative electrical charge." Research[1] has shown that HOCl is 80 times more effective than OCl ion in the inactivation of E. coli and about 150 times more effective for cysts of E. histolytica.

The primary impact on evaluation of chlorination is to note that the CT relationship increases with pH. Contact time, or the T portion of the CT relationship, is controlled by structural facilities (i.e., a contact basin, storage tank, or transmission main) which cannot be adjusted in size to compensate for a needed increase in CT. Therefore, the only alternative is to increase chlorine concentration, or if pH is such that OCl^- is the predominant form, it may be necessary to adjust pH to a lower desirable level so

that HOCl is the predominate form. Adjustment of pH should be considered when the chlorine concentration requirement becomes excessive and possibly objectionable.

Chlorine hydrolyzes very rapidly in water, hydrolysis occurs in tenths of a second at 65°F and a few seconds at 32°F. Although temperature has very little effect on chlorine's ability to go into solution, the reaction of chlorine with microorganisms is affected. CT relationships are inversely related with water temperature, and as the temperature decreases the product of CT increases (Table 1). Therefore, water temperature is important and must be considered when selecting a bactericidal, viricidal, or cysticidal chlorine dosage.

C. Interferences

When chlorine is introduced into water, it not only reacts to form microbiocides but also reacts with other substances to form organic and inorganic compounds that have little or no microbiological inactivating capability. The reaction with organics and inorganic substances constitutes chemical interference with disinfection through consuming a part of, or all of, the applied chlorine leaving little or no chlorine to react as a disinfectant. Organic and inorganic forms of nitrogen are among the compounds that exert a significant interfering effect with chlorination of surface water. Hydrogen sulfide, iron, and manganese are commonly found in groundwaters and interfere with disinfection by combining with chlorine to form sulfates, ferric hydroxide, and manganese dioxide respectively. The significance of this interference is exemplified by the requirement of 8.32 mg/L of chlorine to oxidize 1 mg/L of hydrogen sulfide[1]. In fact, the ability of

chlorine to oxidize hydrogen sulfide, iron, and manganese is used to advantage as a treatment technique and is employed at some water plants for removal of these substances.

Microorganisms entrapped within the matrix of particulate matter are shielded from the effects of chlorination, and this constitutes physical interference. Research[6] indicates that the protective effect of shielding by inorganic particulates is minimal and of little consequence as physical interfering substances; however, organic particulates such as those associated with sewage effluent solids, do afford protection and permit survival of microorganisms after long chlorine contact periods (60 minutes). A recent study by LeChevallier et al.[6] on survival of coliform organisms in the presence of turbidity indicated after one hour of contact time there was 99.5 percent reduction at a concentration of 6 nephelometric turbidity units (NTU's) or less and approximately 20 percent reduction at a concentration of 8-13 NTU's. It was concluded that turbidity control to at least the 1 and 5 NTU concentrations as required by the EPA regulations is justified. While more research is needed to specifically define the degree of physical interference by turbidity and particulates, common sense dictates that where sewage discharges affect raw water quality, turbidity should be reduced by appropriate treatment in order for chlorination to be effective. Appropriate treatment to reduce turbidity normally requires structural measures (mixing, coagulation-flocculation, settling, filtration) which if not already in place require considerable time for planning, design, and construction. In an outbreak situation, emergency short-term measures must be implemented and if chlorination is the only treatment provided, it will have to be adjusted to compensate for the physical interference of turbidity.

An example is provided to illustrate the procedure that should be used in optimizing chlorination to cope with a pathogen challenge. An outbreak of illness caused by a protozoan parasite occurs in a community using an impoundment on a mountain stream as a source of supply. There are no sources of human contamination in the watershed. Chlorination is provided at the impoundment with contact time occurring in 5000' of 24" transmission main. The average daily demand is 2 MGD which is increased by 50 percent during peak usage periods. Temperature of the water is 5°C, pH is 7 and turbidity is 1 NTU. Research data indicate the CT is 100. The chlorine dosage requirement is calculated for peak output, and it has been assumed that the chlorinator feeds in proportion to flow.

Peak Output: 2 MGD x 150% = 3 MGD

Contact Time: $\frac{2350 \text{ gal}^a}{100 \text{ ft}}$ x 5000 ft/3 MGD = 0.039 days

0.039 days x 1440 min/day = 56 min

Chlorine Demand: Test with chlorine comparator kit yields a demand of 0.5 mg/L at 56 minutes

Chlorine Dosage Requirement: Dosage = $\frac{CT}{T}$ + Demand

$= \frac{100}{56} + 0.5$

$= 1.8 + 0.5$

$= 2.3$ mg/L

[a] from Table 1

The calculations account for all factors affecting chlorination except for extrapolating the CT relationship from laboratory research data to applied use. An increased dosage of 0.5 to 1.0 mg/L would not be unreasonable and for this example a dosage of 3 mg/L might be chosen to account for unknown

variables in extrapolation. Increasing the dosage to 3 mg/L has the effect of adjusting the CT relationship by 40 percent (i.e., 1.8 + 0.7 x 56 = 140). The free chlorine residual that is produced, 2.5 mg/L after 56 minutes of contact time, should be confirmed by monitoring.

The above example assumes a flow-proportioning chlorinator which automatically adjusts dosage in response to changes in plant output. Where a constant feed chlorinator is used, several adjustments in dosage are required throughout the course of the day. For example, between the hours of 10:00 p.m. and 6:00 a.m. customer demands decrease and plant output responds accordingly. If demand decreases to 50 percent of the average, the chlorine residual, is going to increase to objectionable concentrations unless the dosage is adjusted. With a 50 percent decrease in average output or 1 MGD and the chlorinator adjusted to maintain the 3 mg/L dosage calculated for 3 MGD, the chlorine residual is going to increase dramatically during low demand hours to 8.5 mg/L. In this example the resulting chlorine residual would likely cause widespread consumer complaints of tastes and odors.

Equally as important as providing the correct dosage is assuring that reliable chlorination is in operation 24 hours per day. Reliability demands dual cylinder feed, auxiliary power, standby equipment and spare parts, and maintenance of records documenting operation. Dual cylinder feed is necessary to ensure continuous dosage so if one cylinder becomes depleted there is an automatic switching to the fully-charged one. A dual cylinder hookup also is needed to ensure continuous feed during cylinder replacement. Changing an empty cylinder for a full cylinder requires about 30 minutes, and if a dual hookup is not provided, unchlorinated water will enter the distribution net-

work. For a plant output of 1 MGD, 21,000 gallons of unchlorinated water would be distributed during these 30 minutes. Auxiliary power is necessary to sustain operation during power outages. A standby chlorinator and spare parts are needed for uninterrupted operation during maintenance and repairs. Records to substantiate reliability in operation including pounds of chemical used, plant output on a daily basis, and chlorine residual measurements are also required. Current technology to ensure reliability in chlorination utilizes loop-controlled feed with remote sensing and automatic adjustment of dosage to a predetermined residual. The residual is continuously analyzed and recorded on circular or strip chart and an alarm system can be installed to warn of low residuals. The continuous record substantiates chlorination, or lack of it, and is a very important factor in verification of proper disinfection.

If treatment cannot be made capable of responding to various challenges within a short period of time, emergency measures such as a boil water order must be implemented to protect against possible waterborne transmission of disease. Boil water orders are not popular because they shift responsibility for providing safe water from the water utility to the consumer, they cause inconvenience for the consumer and are often ignored. They are a nagging problem for regulatory agencies in assuring protection of public health because the agencies are unsure of the degree of compliance with the order and have no means of enforcing it. Other short term measures which can provide safe water during an investigation or during the time required to implement treatment changes include use of bottled water, water from tank trucks, or emergency treatment by mobile units. In instances where bottled water or

tank trucks are used, provisions should be made for evaluating the sources of water and ensuring containers and tanks are free of contamination.

III. EVALUATION OF THE WATER SYSTEM (Priority 2 if cases are not occurring)

An engineering evaluation of the water system including source, treatment, and distribution is required to identify sources of contamination, defects in facilities, and failures in operation that may have contributed to the cause(s) of the outbreak. The statistics presented in Chapter 6 should be used as a reminder of the historical causes of outbreaks but it is important to keep an open mind in conducting a thorough, objective evaluation, as previously undetermined or unimportant causes of outbreaks may be responsible. The engineer should familiarize himself with the physical layout of the system, how it is operated, and any peculiarities that may be related to time or place with onset of illness. Findings from the evaluation should be quickly communicated to others involved in the investigation, especially the epidemiologists, so that they are aware of the time of failures in operation, equipment breakdowns or other events that may impact on the outbreak investigation.

A number of references[1,5-13] provide useful background information for evaluation of water systems, however, there is no substitute for experience gained through conducting on-site surveys of systems, preparing a written report, and defending the report and recommendations which frequently require capital improvements or an increase in operating budget.

A. Source of Supply

Two components are required to precipitate a waterborne disease outbreak. There must be a source of contamination and a route-of-entry for the contaminant to penetrate the water system. Statistics overwhelmingly show that outbreaks are caused when the source of water supply is affected by a contaminant and the treatment which is provided is inadequate or is overwhelmed, thus permitting entry of the contaminant into the distribution network (Figure 48, Chapter 6). The source of contamination may be active on a continuous, intermittent, or sporadic basis. It may be a point source or a non-point source, and it may be visible or not visible. Table 3 lists the principal sources of contamination and the contaminants of concern.

When an actual or potential source of contamination has been identified testing may be required to show that it is influencing water quality, or it may be so obvious[14] that the impact is apparent. Intermittent or sporadic contaminants and sources of contamination which are not readily apparent or not visible may require lengthy and more complex testing to determine impact on raw water quality. Dye-testing has been used successfully in a number of outbreaks to document contamination of wells and springs by septic tanks and a wastewater disposal pond. Rather dramatic results were obtained in a viral gastroenteritis outbreak in Colorado[15] when dye introduced into a septic tank through a cabin toilet appeared in a spring in less than one hour. The spring served as a source of water supply for a 3000 acre resort camp and also as a source of illness for 418 visitors. Similar but not quite as dramatic results were obtained in a shigellosis outbreak in Florida affecting 1200 persons.[16] Dye introduced into a septic tank through a church toilet appeared in a well serving the community in nine hours. Persistence and

perserverance paid off in an outbreak of gastroenteritis in Missouri where 219 persons became ill after visiting a restaurant. The restaurant was served from a well that was contaminated by a wastewater disposal pond. Dye appeared in the restaurant well 529 hours or 22 days after it was introduced into the pond.[17] In situations involving groundwater sources, and especially in water systems served by a number of wells, it is helpful to collect samples of raw water for coliform analysis to determine if any are influenced by indicator organisms. This procedure aids in isolating a trouble spot for further extensive testing. In situations where animals served as a source or vehicle for contaminants, trapping and necropsy have been used to trace the source of contamination.[4,18]

It is to the investigator's advantage to identify and confirm sources of contamination so that epidemiologic investigations can be strengthened, sources removed, and required treatment provided. Devoting sufficient time to this part of the water system evaluation is especially rewarding if efforts are successful. Sources of contamination can either be halted or treated, use of the raw water that is affected can be terminated, or the water can be treated to offset the challenge. Finding the source of contamination presents the investigator with more alternatives in developing solutions. Where the source is not found, doubt lingers as to whether there will be recurrence even when precautionary and corrective measures supposedly address all conceivable challenge situations.

B. Treatment

Evaluation of treatment should include an inspection of facilities and a review of operating records to determine whether the plant is functioning

properly. It is normally easier to understand treatment and operation if the inspection is conducted as water flows through the plant from raw water intake to finished water outlet. A schematic diagram should be drawn showing treatment units including mixing, coagulation-flocculation, settling, filtration, chlorination, points of chemical addition, and appurterant units including intake, clearwell, pumping, etc. Information on unit size, volume, capacity, condition, age, and maintenance should be noted. Type, frequency, and records for operational monitoring and control should be obtained for review. Data on plant output, chemical dosage, operational down-time due to maintenance, failure, power outage, or other reasons should be collected. The epidemiological information should be used to identify a critical period of time when consumers were likely exposed to the contaminant and treatment information for that period should be detailed and specific.

Chemical dosage for coagulation, pH control, and disinfection should be plotted versus time to compare plant response with changes in water quality and plant output.[19] The comparisons should show that increases in raw water turbidity are accompanied by increases in use of coagulants, and an increase in plant output is accompanied by an increase in the use of chlorine. The plotted data can reveal lapses in operation that may coincide with the critical period or it may simply provide an insight on how poorly or well the plant is operated.

Table 4 lists information, guidelines, and simple tests that can be used in plant inspections to determine operational characteristics. Analysis of operating records and results of the plant inspection should reveal weaknesses

that may permit a contaminant to penetrate the treatment train and enter the distribution network.

C. Distribution

The distribution network is the most difficult component of the water system to evaluate since nearly all of it is underground. Facilities that are visible including chlorine booster stations, storage reservoirs, and pumping stations should be inspected. Since these facilities are unmanned and are visited only periodically by operators and maintenance personnel, they are vulnerable to periods of inoperation. Records should be reviewed for down-time that may coincide temporarily with the outbreak. Unmanned facilities also are vulnerable to illegal entry which may be responsible for inoperative periods or contamination.

Other information that may be related to the critical time period should be collected including repair of main breaks, installation of new lines and services, recent construction work on the sewerage system, community events with a large number of visitors creating unusual demands on the system, occurrence of fires, and consumer complaints of low pressure, dirty, discolored or strange tasting water.

The engineer should gain an understanding of how water is distributed in the community especially noting pressure zones, areas of the network that are isolated by valves, any sections that are served water from a different source, and any interconnections with other water supplies. Residences or establishments that maintain connections with the water system and have privately-owned sources of supply, such as a well used by a homeowner for

irrigation, should be noted and inspected. Areas of low pressure should also be examined for possible cross-connections. It is sometimes possible to re-create events to demonstrate the occurrence of backsiphonage under conditions of low or negative pressure.[20]

The information gained through familiarization with the distribution network will be useful in establishing an association by time or place with cases of illness. Spotting cases of illness on a map of the distribution network may show clustering that can be explained by a specific service area, equipment malfunction, main break, source of contamination, reservoir, peculiar event, or other happening that relates to a specific time or place of occurrence.

IV. SAMPLING FOR THE AGENT (Priority 3 if cases are not occurring)

If the outbreak is quickly recognized and initiation of an investigation is timely, the investigators may be fortunate in identifying the causative agent in samples collected from the water system. Historically, the success of this occurring is very poor. In less than one per cent of the outbreaks has the etiologic agent been identified in water samples. Investigators have a better chance of identifying the agent through analysis of clinical specimens from infected individuals. Microbiological agents multiply in the intestinal tract and are shed in large numbers which provide for better opportunities in isolating and identifying bacteria, viruses or parasites in stool specimens. Conversely, the opposite occurs in water systems where microbiological agents die away in a hostile environment or are diluted in number to a concentration not detectable by current technology. Detecting the agent in the water system is a very convincing piece of evidence and

contributes substantially to the success of the investigation. It not only strengthens the epidemiological evidence that an outbreak is waterborne but also supports the engineer's evaluation of the weaknesses in the water system that require correction.

Collection of water samples for bacteria, virus or protozoa should be guided by the epidemiological evidence or health authority's appraisal of the etiological agent. Large volume sampling techniques[21] capable of isolating the agent from 100-500 gallons of water have been developed for virus and parasites and should be used to increase the chances for capture. Specific sample volumes for bacteria are not determined but normally are limited by the suspended solids concentration of the water being sampled and clogging of the sampling device. Microbiological overgrowth of culturing media occurs and also interferes with analysis of large volume samples for bacteria. The extent of sample collection is determined by the capability of the laboratory doing the analyses and the accompanying expense.

One of the drawbacks of identifying the causative agent for some pathogens is the length of time required for analysis. Viral assays are especially time consuming and in some cases several months are required for identification. While this should not detract from sample collection efforts it does serve to dampen spirits for quickly determining the cause of illness in the community and does not help in allaying the immediate concern and fear of people who were stricken.

The engineer through his evaluation of the water system and interpretation of information provided by the epidemiologist can assist in selecting

the sampling locations. If the source of water supply is suspected as being contaminated, sampling of surface or groundwater sources should be conducted. Single or multiple sources of actual or potential contamination identified in Table 3 can be sampled to document active discharges. Bracketing a discharge location through upstream and downstream sampling provides a comparison of results to help identify a source of contamination. For example, a river used as a source of supply may have a creek tributary influenced by a waste discharge. Bracketing the tributary through river samples may show elevated coliform counts and indicate further sampling of the creek to identify the source of contamination. If a water system is served by a number of wells, raw water at each well should be sampled for indicator organisms to aid in isolating a trouble spot for follow-up and for large volume sampling for pathogens.

Through evaluation of treatment the engineer will be familiar with the weaknesses, and selection of sampling sites may be dependent upon bracketing the weakness to show that a process can be penetrated if challenged. Sampling filter effluent at the beginning of a run (immediately after backwash) for indicator organisms coupled with a breakdown or interruption in chlorination (changing cylinders) would show the effects of filter spike and the plausibility of pathogen challenge and penetration. If treatment is marginal or inefficient for removal and inactivation of indicator organisms, raw and finished water samples for coliform and pathogens should be collected to show challenge and possible penetration.

Collection of samples from the distribution network should be guided largely through the analysis of epidemiological data. If cases of illness

are predominantly in one area of the distribution network and localized contamination is suspected, samples should be collected in hopes of identifying the source. An open reservoir or well serving that area of the community may be the trouble spot and collection of appropriate samples should be conducted for indicator organisms as well as the causative agent.

If the outbreak has subsided before the investigation begins and there have not been any recent cases of illness there is always the possibility of stored water still available from the critical period. Contaminated water still might be present if the water utility has valved off a reservoir or isolated a main for repairs. Swimming pools may have been filled and, if not chlorinated, may still harbor the agent. Pumper trucks from the local fire department may have filled tanks during the outbreak and could be a sampling source. Ice frozen during the outbreak should be considered as a source for identification of virus and parasites. Investigators should keep this in mind when initiating public health measures to prevent further illness from occurring. Ice from the critical period should not be used if a viral agent is suspected of causing the illness since they do survive freezing.

V. COMMUNICATION

During the investigation of the outbreak there is a need to exchange information among the participants and to communicate progress and results to the community. Frequent meetings of the participants are necessary so that all are informed of what others are doing to avoid duplication of effort and to prevent the "I thought you were going to do it" syndrome. It is important that the investigation proceed with a team effort with all members carrying out their assignments and reporting periodically to a team leader. The team

leader should act as a spokesperson communicating progress and results of the investigation to local authorities and the community. There should be early agreement between the team leader and local authorities on the methods of communicating with the community through the news media. Depending on the situation, it may be necessary for the team leader to communicate either directly, jointly, or indirectly through a local official. The situation can range from one of local officials not feeling comfortable with translation of scientific terminology and results and thus depending on the team spokesperson for periodic release of information through interviews, press conferences, etc., to one where a local governing body may have its own public affairs office which handles all communication with the press and community. It is especially important that investigators be aware of the local situation and act accordingly to ensure that communication does not bypass or ignore traditional methods.

It is the engineer's responsibility to communicate his activities and findings to the team leader and local authorities. He should be especially careful that findings are interpreted correctly and engineering terminology does not interfere with the understanding of the evaluation of the water system. Words and terms commonly used and understood by public health workers are uncommon and misunderstood by the public and the news media. Coliform, pathogen, etiological agent, epi-curve, contact time, and pH are examples which often require definition and explanation in order that findings are interpreted correctly. Without explanation, positive coliform results may appear in the press as "cauliflower" in the water. Persons interviewed by the press soon become known as "experts" and sometimes make the mistake of believing it. The belief leads to answering questions beyond the "expert's"

capability rather than referring the question or responding, "I don't know but will find the answer for you". The temporary embarassment of not knowing everything is much preferred to the problems encountered with explaining and correcting erroneous statements appearing in print.

The engineer's written report of evaluation and findings should be complete but not necessarily lengthy. It should include a description of the water system and how it is operated, specific discussion of weaknesses or deficiencies that contributed to occurrence of the outbreak, identification of the route-of-entry of the contaminant, actions that were taken to abate the outbreak, description of tests or analyses that substantiate breakdowns in operation of facilities, a summary/conclusion section followed by recommendations for improvements that may address both short- and long-term needs. The form and content of the written report reflects individual professional style and may vary considerably for different situations. However, it should be written in a manner that it is understood by those who are expected to implement the recommendations and can be understood by the general public to aid in gaining community acceptance for the recommendations. Therefore, submitting a draft of the report for review prior to the final report may be helpful in avoiding misunderstanding.

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TABLE 1

Chlorine Concentration - Contact Time (CT) Relationships

for 99% Inactivation of Pathogenic Agents

Water pH	Viral CT		Protozoan CT		
	0 - 5°C	10°C	5°C	15°C	25°C
6			80	25	15
7			100	35	15
7.0 - 7.5	12	8			
7.5 - 8.0	20	15			
8			150	50	15
8.0 - 8.5	30	20			
8.5 - 9.0	35	22			

TABLE 2

Fluid Capacity of Pipes - Gallons/100 ft. of Length

Pipe Diameter (d) (inches)	Capacity[a] (gals/100 ft.)
3	37
4	65
6	147
8	261
10	408
12	588
14	800
16	1044
18	1322
20	1632
24	2350
30	3672
36	5288
42	7197
48	9400

a $4.08d^2$

TABLE 3

Sources of Contamination

Source	Contaminant
Point Sources	
1. Waste Water Treatment Plant (domestic & industrial)	C,B,V,P[a]
2. Water Treatment Plant (backwash, sludge, spills)	C,B,V,P
3. Septic Tanks	B,V,P
4. Feed Lots (with treatment/holding facility)	B,V,P
5. Sewerage Systems (overflows at pumping stations and manholes, damaged pipes)	C,B,V,P
6. Highways, Railroads (spills)	C
7. Beaver Lodges	P
8. Cross-connections	C,B,V,P
Non-Point Sources	
9. Agricultural	
a. Livestock grazing	B,V,P
b. Application of chemicals (herbicides, pesticides, weedicides)	C
c. Application of Fertilizer (manure, sludge, chemical)	C,B,V,P
10. Power Line Right-of-Way (spraying)	C
11. Forests (spraying)	C

[a] C - chemical, B - bacteria, V - virus, P - parasite.

TABLE 4

Guides for Plant Inspection[a]

Process	Guides	Remarks
Mixing		
Rapid Mechanical	Detention: 30 sec	10-20 sec. not uncommon
		$\left(\frac{\text{Basin Volume}}{\text{Flow}} = \text{detention}\right)$
	Drive motor: 1-2 HP/CFS	$G = \left[\frac{P}{\mu V}\right]^{1/2}$
	temporal mean velocity gradient or "G" factor: 500-1000 sec^{-1}	where:
		P = power to H_2O in ft lb/sec
		μ = absolute viscosity[b] in lb sec/ft^2 and varies with H_2O temperature
		V = volume of basin in ft^3

[a] For conventional plants, high-rate units may be different

[b] μ @ 0°C = 3.74×10^{-5}

μ @10°C = 2.73×10^{-5}

μ @20°C = 2.11×10^{-5}

TABLE 4 (Cont.)

Guides for Plant Inspection

Process	Guides	Remarks
Hydraulic	Efficiency varies with plant output	Turbulence decreases at low plant output during off-demand hours. Operator has little control over the process.
Coagulation-Flocculation	Detention: 4 hrs.	$\left(\frac{\text{wetted basin volume}}{\text{flow}} = \text{detention}\right)$ Check detention with tracer test[2]
	Flow-thru velocity: 0.5 - 1.5 ft/min	$\left(\frac{\text{flow}}{\text{wetted cross section}} = \text{velocity}\right)$
	P.P.S. or peripheral paddle speed: 0.5 - 2.0 ft/sec	$\left(\frac{\text{perimeter of unit}}{\text{time of 1 revolution}} = \text{PPS}\right.$

TABLE 4 (Cont.)

Guides for Plant Inspection

Process	Guides	Remarks
Clarification		
Sedimentation	Detention: 4 hrs	$\left(\frac{\text{wetted basin volume}}{\text{flow}} = \text{dention}\right)$
		Check detention with tracer test[2]
	Flow-thru velocity:	$\left(\frac{\text{flow}}{\text{wetted cross section}} = \text{velocity}\right)$
	<0.5 ft/min	
	Overflow rate:	$\left(\frac{\text{Weir length}}{\text{daily flow}} = \text{overflow rate}\right)$
	>20,000 gals/day/ft	
	of Weir length	Swirls, eddies, currents indicative of short-circuiting causing suspension of sediment and carryover to filters.
Filtration	Control of spike	Turbidity measurement @10 min intervals for one hour when backwashed filter is put on line.

TABLE 4 (Cont.)

Guides for Plant Inspection

Process	Guides	Remarks
	Control of bumping	Monitor filter effluent during run for turbidity to detect sudden increases followed by decreases.
	Uniformity of media	Conduct sieve analysis and determine uniformity coefficient.
	Loss of media	Check measurements from top of filter box to top of media against dimensions of engineering plans or "as-built" drawings or check staining of walls in filter box.

TABLE 4 (Cont.)

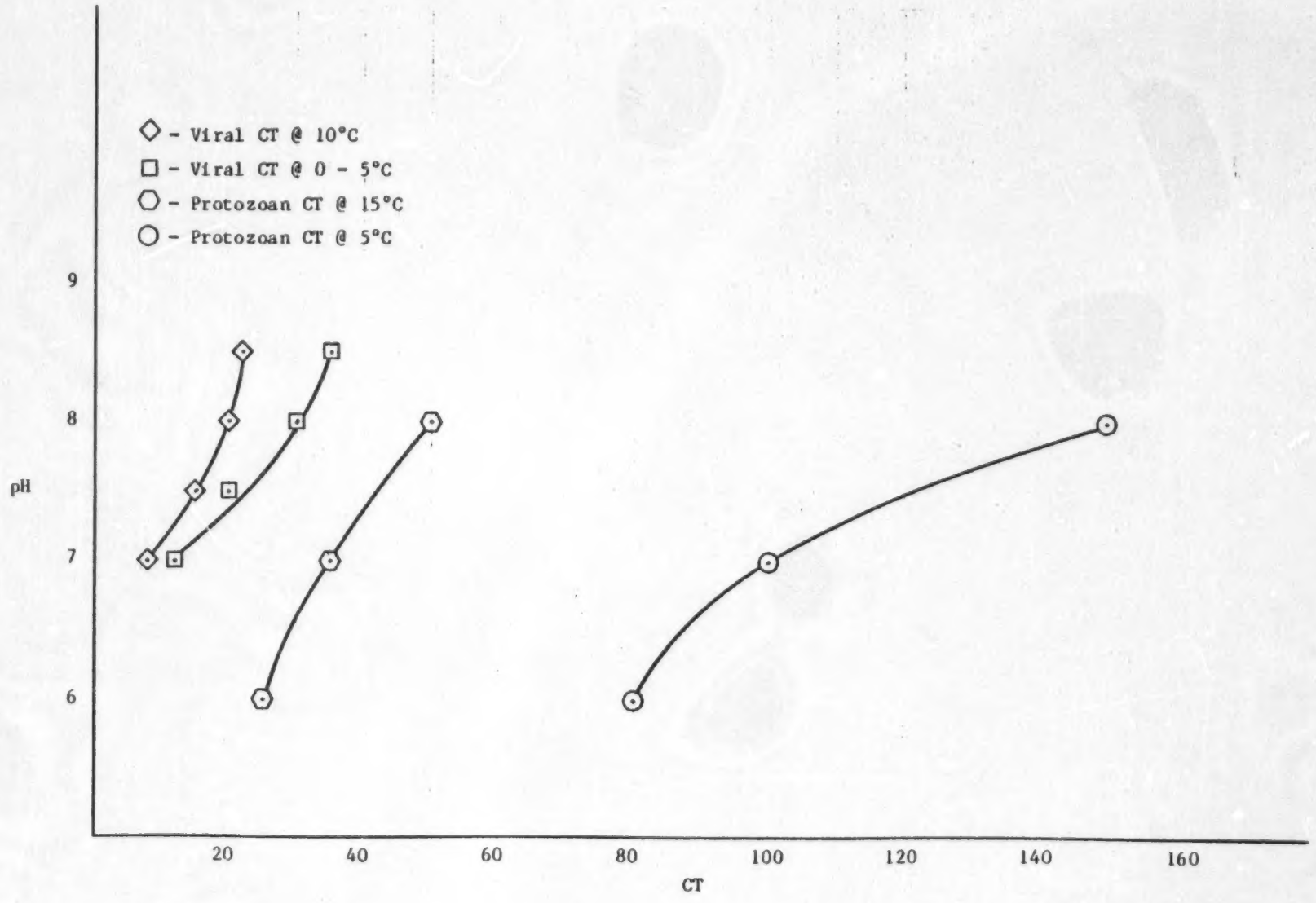
Guides for Plant Inspection

Process	Guides	Remarks
	Effectiveness of backwash	Visual inspection for even media surface; collapse of media away from walls and surface cracks; uniform dispersal and absence of "boil"; measurements for 25-30% bed expansion during backwash; and analysis for mud ball concentration.[4]
Disinfection	Concentration Contact Time	See text Part II A
	pH Temperature	See text Part II B
	Interferences	See text Part II C

Figure 1

Chlorine Concentration - Contact Time (CT) Relationships

for 99% Inactivation of Pathogenic Agents


◇ - Viral CT @ 10°C
□ - Viral CT @ 0 - 5°C
⬡ - Protozoan CT @ 15°C
○ - Protozoan CT @ 5°C
9
8
7
6
pH
20
40
60
80
100
120
140
160
CT